1-1-2013

Process design strategies for producing heavy section steel with improved quality

Jingwei Zhao
University of Wollongong, jzhao@uow.edu.au

Zhengyi Jiang
University of Wollongong, jiang@uow.edu.au

Dongbin Wei
University of Wollongong, dwei@uow.edu.au

Chong Soo Lee
Pohang University of Science and Technology

Process design strategies for producing heavy section steel with improved quality

Abstract
Uniformity of microstructure and mechanical properties is required for the heavy section steel. In the present work, a heavy section wind tower flange was manufactured by controlled ring-rolling. Post-rolling heat treatment was employed to optimize the microstructure and mechanical properties. The chemical composition, microstructure and mechanical properties in different zones of the flange were investigated. The results showed that the chemical composition and microstructure were uniformly distributed in the flange. The tensile strength showed similar values in different sampling locations. The strain and impact energies of specimens prepared along the longitudinal direction were higher than that prepared along both the radius and thickness directions. Notch direction did not have noticeable effect on the impact energy. It is demonstrated that the designed process is effective for producing heavy section steel with improved quality.

Keywords
heavy, steel, section, producing, strategies, design, process, improved, quality

Disciplines
Engineering | Science and Technology Studies

Publication Details
Zhao, J., Jiang, Z., Wei, D. & Lee, C. Soo. (2013). Process design strategies for producing heavy section steel with improved quality. Advanced Materials Research, 652-654 988-991.

Process Design Strategies for Producing Heavy Section Steel with Improved Quality

Jingwei Zhao[1,a], Zhengyi Jiang[1,b], Dongbin Wei[1,c] and Chong Soo Lee[2,d]

[1]School of Mechanical, Materials and Mechatronic Engineering, University of Wollongong, Wollongong, NSW 2522, Australia

[2]Graduate Institute of Ferrous Technology, Pohang University of Science and Technology, Pohang 790-784, Republic of Korea

[a]jzhao@uow.edu.au, [b]jiang@uow.edu.au, [c]dwei@uow.edu.au, [d]cslee@postech.ac.kr

Keywords: Heavy section steel, Process design, Microstructure, Mechanical properties

Abstract. Uniformity of microstructure and mechanical properties is required for the heavy section steel. In the present work, a heavy section wind tower flange was manufactured by controlled ring-rolling. Post-rolling heat treatment was employed to optimize the microstructure and mechanical properties. The chemical composition, microstructure and mechanical properties in different zones of the flange were investigated. The results showed that the chemical composition and microstructure were uniformly distributed in the flange. The tensile strength showed similar values in different sampling locations. The strain and impact energies of specimens prepared along the longitudinal direction were higher than that prepared along both the radius and thickness directions. Notch direction did not have noticeable effect on the impact energy. It is demonstrated that the designed process is effective for producing heavy section steel with improved quality.

Introduction

The capacity of wind power energy improves with tower height. The wind power industry is growing with the trend towards taller towers and larger turbine capacity. Heavy section flanges with improved quality are required to improve the load bearing of the wind towers [1,2]. Wind tower flange is traditionally produced by hot forging. Forging is regarded as one of the most important processes to manufacture products with good mechanical properties and fine metallurgical structures [3]. Today, systematically designed forging processes are being performed in controlled process and hammers to produce forged shapes with high dimensional accuracy and structural integrity. However, as steel ingots increase in diameter, non-uniformly distributed microstructure and mechanical properties become more serious. In order to obtain improved mechanical properties in the whole volume of the forging, dies with a special shape must be used [4]. Three types of dies are usually used in elongation forging: flat, shaped and a combination of both [5]. The flat dies give the best degree of deformation on the whole cross-section of the ingot. However, they also involve relatively large non-uniformity of deformation, yielding non-uniformly distributed mechanical properties of the product. Since the dimensions of the final forging are larger compared to the stock ingot, the additional operation of upsetting is usually performed in order to increase the amount of hot deformation. Upsetting prior to elongation is efficient in improving the microstructure of the product, but it leads to increased production costs.

The specific requirements for heavy section wind tower flanges are to give high qualities of uniform chemical composition, microstructure, tensile properties and impact toughness. Proper design of producing process is essential to achieve the desired mechanical properties. In this study, a controlled ring-rolling technology was introduced to manufacture the heavy section wind tower flange. The effects of heat treatment after ring-rolling on the microstructure and mechanical properties at different locations of the flange were investigated. The objective of the present work was to acquire the uniformly distributed chemical composition, microstructure and mechanical properties of the heavy section flange through designed producing process integrated with ring-rolling and post-rolling heat treatment.

Experimental Procedures

The material used in this study was a microalloyed steel. The designed chemical compositions were as follows: (wt.%): 0.17 C, 1.3 Mn, 0.15 Cr, 0.25 Ni, 0.1 Cu, 0.2 Si, 0.03 Al, 0.02 V, 0.04 Nb, 0.01 Co, 0.05 Mo, 0.01 P, 0.005 S and the balance Fe. Casting ingot was heated to 1230□ for a period of time and then ring-rolled to be a heavy section flange with dimensions of 3.7 m in inner diameter, 0.15 m in thickness and 0.19 m in height followed by air cooling. The holding time was determined by 1 h/50 mm. The final rolling temperature was controlled to be higher than 950□. The flange was heated to 880□ at a rate of 100□/h, and then held for 4 h followed by air cooling, as illustrated in Fig. 1. Heat treatment was carried out using a large-scale industrial furnace. Samples were prepared from the surface and central zones along longitudinal (LS, LC), thickness (TS, TC) and radius (RS, RC) directions of the flange, as shown in Fig. 2.

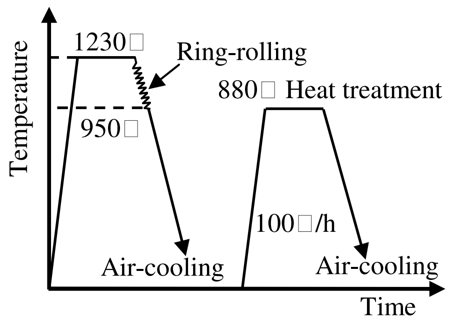

Fig. 1 Schematic illustration of the ring-rolling and heat treatment processes.

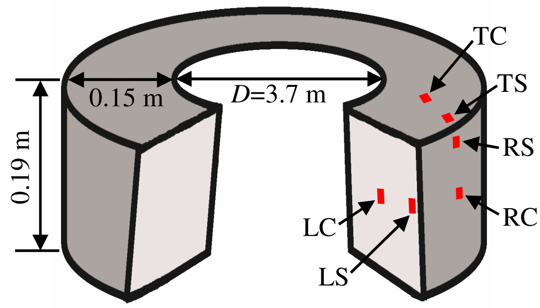

Fig. 2 Dimension of the wind tower flange and the sampling locations.

The real chemical compositions were analysed by a spark atomic emission spectrometer. Optical microscope (OM) was used to identify microstructure. Standard tensile and Charpy impact specimens were machined according to ASTM E 8M (Gauge length 30 mm, gauge diameter 6 mm) and ASTM E 23 (cross section 10×10 mm, length 55 mm, notch angle 45°, notch depth 2 mm), respectively. Tensile tests were performed on an INSTRON 8801 tensile testing machine at room temperature with strain rate of 5×10^{-3} s^{-1}. The resulting stress-strain curves were analysed to determine the yield stress (YS) and ultimate tensile stress (UTS). A Zwick/Roell impact tester was employed to study the room temperature impact toughness. Fracture surfaces of the tested specimens were examined on scanning electron microscope (SEM) using an accelerating voltage of 15 kV to determine the failure mode.

Results and Discussion

Real Chemical Composition. Table 1 shows the real chemical compositions of specimens LS and LC. It can be seen that both specimens have almost the same chemical compositions. Uniformly distributed chemical compositions have been obtained after ring-rolling and post-rolling heat treatment.

Table 1 Real chemical compositions of the studied steel (wt.%)

Specimens	C	Mn	Cr	Ni	Cu	Si	Al	V	Nb	Co	Mo	P	S
LS	0.158	1.34	0.154	0.256	0.101	0.232	0.029	0.023	0.037	0.008	0.049	0.013	0.005
LC	0.160	1.33	0.154	0.258	0.101	0.233	0.029	0.023	0.036	0.008	0.049	0.013	0.005

Microstructure. Fig. 3 shows the microstructures of specimens prepared along longitudinal, thickness and radius directions of the flange. It can be seen that all the microstructures consist of ferrite and pearlite, and the distributions of ferrite and pearlite are very uniform. Along the longitudinal direction, the microstructures in both the surface and central zones show similar grain size, as shown in Fig. 3a and d. For the specimens prepared along the thickness and radius directions, finer grains are observed in the surface zones (Fig. 3b and c) relative to that in the central zones (Fig. 3e and f). In the surface zones, the grain sizes in specimens RS and TS are smaller than that in specimen LS, as shown in Fig. 3a, b and c. In the central zones, the sizes of some grains in specimens RC and TC slightly increase relative to that in specimen LC, as shown in Fig. 3d, e and f.

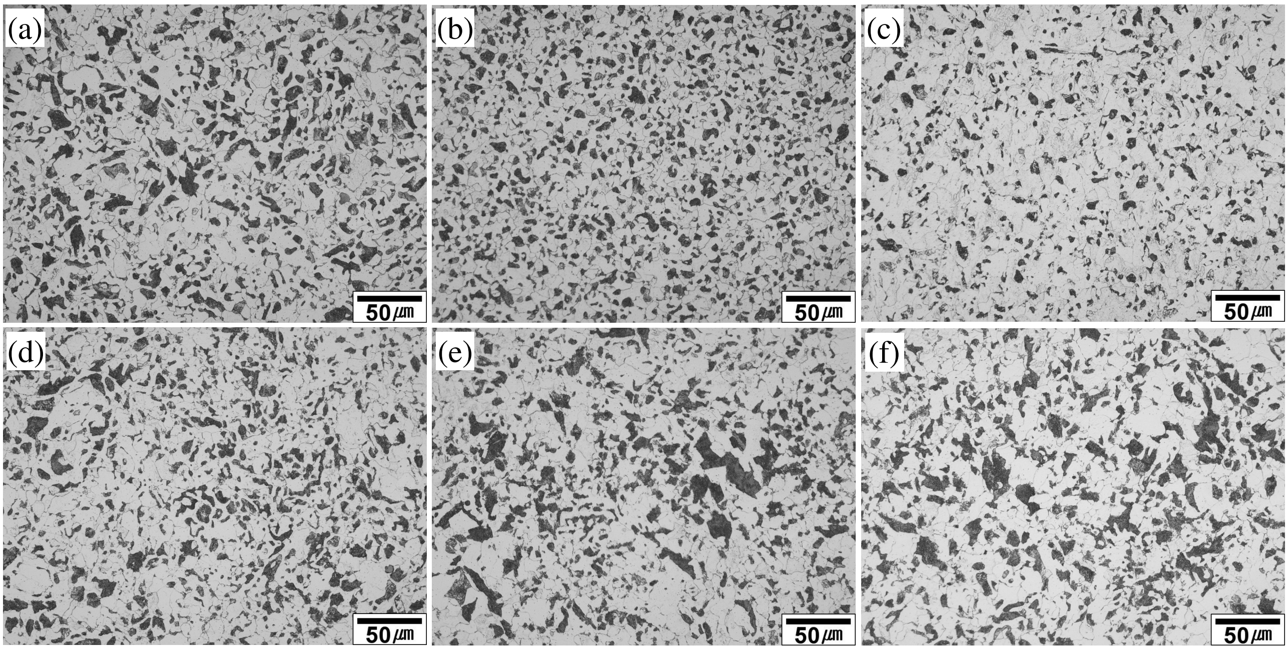

Fig. 3 Microstructures of specimens: (a) LS, (b) RS, (c) TS, (d) LC, (e) RC and (f) TC.

Mechanical Properties. Fig. 4a shows the typical tensile curves of the specimens LC, RC and TC. The tensile properties determined from these curves are presented in Fig. 4b. The Charpy impact energies are illustrated in Fig. 4c. In Fig. 4c, LC(R) means the notch direction in impact specimen LC is machined towards R.

The results in Fig. 4a indicate that the tensile behaviours of the tested specimens are similar, i.e. all engineering stress vs. strain curves with apparent yield points can be simply divided into three stages, such as elastic deformation, plastic deformation and fracture. From Fig. 4b, it can be found that sampling locations do not have noticeable effect on the tensile strength. Differently, specimens RC and TC show lower strains in contrast to specimen LC. The impact energies of specimens prepared along the longitudinal direction are higher than that prepared along both the radius and thickness directions, as shown in Fig. 4c. Moreover, notch direction slightly affects the impact energies.

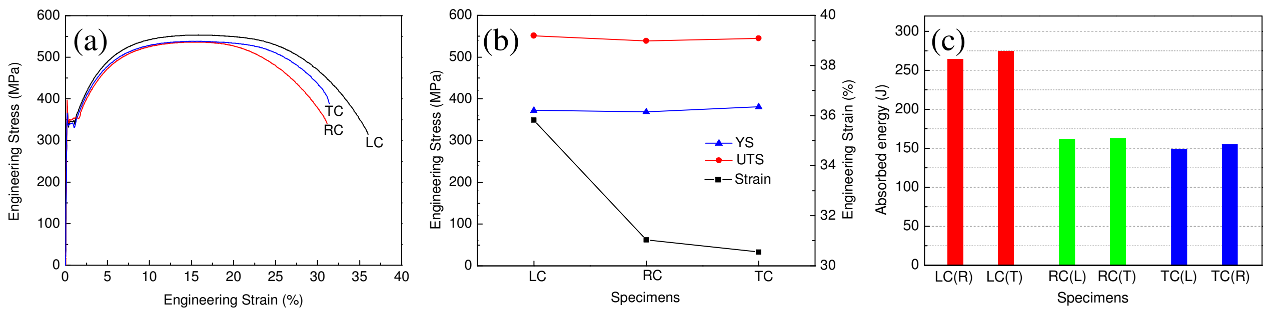

Fig. 4 Mechanical properties of the tested specimens: (a) tensile curves, (b) tensile properties and (c) Charpy impact energies.

In microalloyed steels, the tensile strength is closely related to the grain size. Fine-grained structure has a positive effect on the increment of tensile strength [6]. According to Fig. 3d, e and f, the mean grain size in specimen LC is similar to that in specimens RC and TC. Therefore, no noticeable variation of tensile strength among specimens LC, RC and TC is observed. Directional properties in the ring-rolled flange tend to vary between the longitudinal and transverse directions depending on the relative amounts of rolling work in each direction [7]. The variation in properties is due to directionality in the microstructure from forming operation. RC and TC specimens are prepared perpendicular to the ring-rolling direction, and lower values of strain and impact energy are expected relative to the specimen LC which is machined along the rolling direction.

Fractography. Fig. 5 shows the tensile fracture morphologies of specimens LC and TC. It can be seen that both fracture surfaces are composed of dimples, which shows a characteristic of ductile fracture. Differently, the dimples in specimen LC are deeper in contrast to that in specimen TC, which is consistent with the tensile test results that specimen LC shows higher strain than specimen TC.

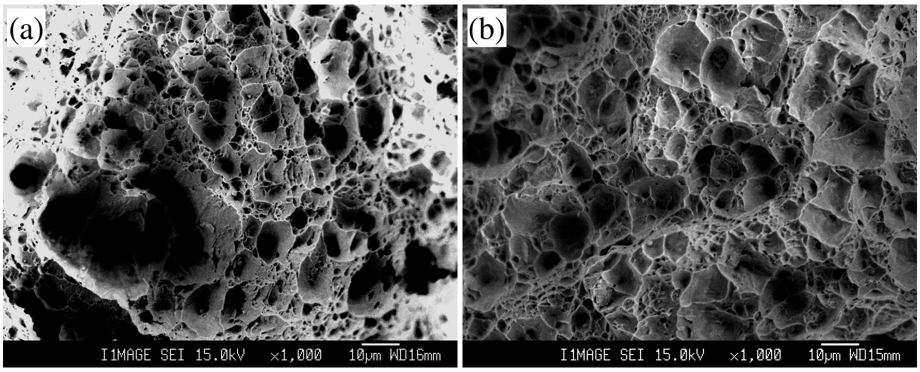

Fig.5 Fracture morphologies of specimens (a) LC and (b) TC after tensile tests.

Conclusions

An integrated process was designed for producing high quality heavy section wind tower flange. The distribution of chemical composition, microstructure and mechanical properties after ring-rolling and post-rolling heat treatment were investigated. The results indicate that the chemical composition and microstructure uniformly distributed in the flange. Sampling locations do not have noticeable effect on the tensile strength. The strain and impact energies of specimens prepared along the longitudinal direction are higher than that prepared along both the radius and thickness directions. Notch direction slightly affects the impact energies. From the tested results, it can be concluded that the designed process can be used to produce high quality heavy section steel.

References

[1] R. Lacalle, S. Cicero, J.A. Alvarez, R. Cicero, V. Madrazo: Eng. Fail. Anal. Vol. 18 (2011), p. 1698.
[2] J.S. Chou, W.T. Tu: Eng. Fail. Anal. Vol. 18 (2011), p. 259.
[3] X. He, Z. Yu, X. Lai: Mater. Des. Vol. 30 (2009), p. 2084.
[4] J. Sinczak, Z. Malinowski, S. Szczepanik: Met. Foundry Eng. Vol. 18 (1992), p. 35.
[5] J. Sinczak, J. Majta, M. Glowacki, M. Pietrzyk: J. Mater. Process. Technol. Vol. 80-81 (1998), p. 166.
[6] D.A. Skobir: Mater. Technol. Vol. 45 (2011), p. 295.
[7] E.G. Nisbett: *Steel Forgings: Design, Production, Selection, Testing, and Application* (ASTM International, 2005).